



CMS-SUS-13-003



CERN-PH-EP/2013-093

2013/07/01

Search for top squarks in R -parity-violating supersymmetry using three or more leptons and b-tagged jets

The CMS Collaboration*

Abstract

A search for anomalous production of events with three or more isolated leptons and bottom-quark jets produced in pp collisions at $\sqrt{s} = 8$ TeV is presented. The analysis is based on a data sample corresponding to an integrated luminosity of 19.5 fb^{-1} collected by the CMS experiment at the LHC in 2012. No excess above the standard model expectations is observed. The results are interpreted in the context of supersymmetric models with signatures that have low missing transverse energy arising from light top-squark pair production with R -parity-violating decays of the lightest supersymmetric particle. In two models with different R -parity-violating couplings, top-squarks are excluded below masses of 1020 GeV and 820 GeV, respectively, when the lightest supersymmetric particle has a mass of 200 GeV.

Submitted to Physical Review Letters

Supersymmetric (SUSY) extensions of the standard model (SM) offer a solution to the hierarchy problem and provide a mechanism for unifying particle interactions [1, 2]. Assigning R -parity [3] to fields as $R = (-1)^{3B+L+2s}$, where B and L are baryon and lepton numbers, and s is the particle spin, all SM particle fields have $R = +1$ while all superpartner fields have $R = -1$. In models where R -parity is conserved, superpartners can only be produced in pairs, and the lightest superpartner (LSP) is stable and could serve as a dark-matter candidate. R -parity conservation also ensures proton stability.

Supersymmetric models with R -parity violating (RPV) interactions necessarily violate either B or L but can avoid proton decay limits [4, 5]. The superpotential W_{RPV} includes three trilinear terms parametrized by the Yukawa couplings λ_{ijk} , λ'_{ijk} , and λ''_{ijk} :

$$W_{\text{RPV}} = \frac{1}{2} \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2} \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k, \quad (1)$$

where i , j , and k are generation indices; L and Q are the $SU(2)_L$ doublet superfields of the lepton and quark; and the \bar{E} , \bar{D} , and \bar{U} are the $SU(2)_L$ singlet superfields of the charged lepton, down-like quark, and up-like quark. The third term violates baryon number conservation, while the first and second terms violate lepton number conservation.

The RPV interactions allow for single production of SUSY particles (sparticles) and for sparticle decay into SM particles only. The latter is explored in this Letter. Prior searches for RPV interactions in multilepton final states include those by the ALEPH [6], DELPHI [7], and L3 [8] experiments at LEP; the CDF [9] and D0 [10] experiments at the Tevatron; and by H1 [11] and ZEUS [12] at HERA. These have been continued by the CMS [13, 14] and ATLAS experiments [15] at the Large Hadron Collider (LHC).

Among modern SUSY models, those characterized as “natural” play a prominent role. Natural supersymmetry is characterized by a relatively small fine tuning to describe particle spectra. In particular, it requires top squarks (stops), the top-quark superpartners, to be lighter than about 1 TeV. The introduction of RPV couplings does not preclude a natural hierarchy and can allow the constraints on the stop mass to be relaxed [16].

In RPV models, the LSP is unstable, and a common experimental strategy of SUSY searches—selecting events with large missing transverse energy (E_T^{miss})—is not optimal [4]. Instead, we use S_T , which is the scalar sum of E_T^{miss} and the transverse energy of jets and charged leptons, to provide separation between signal and standard model backgrounds.

In this Letter we present the result of a search for pair production of top squarks with RPV decays of the lightest sparticle, using multilepton events with one or more bottom-tagged (b -tagged) jets. The data set used in this analysis corresponds to an integrated luminosity of 19.5 fb^{-1} , recorded in 2012 with the CMS detector at the LHC in proton-proton collisions at a center-of-mass energy of 8 TeV.

The coordinate system in CMS is right-handed, with the origin at the nominal interaction point. The x axis points towards the center of the LHC ring, the y axis points up, and the z axis points along the counterclockwise-beam direction. The polar angle θ is measured with respect to the positive z axis and the azimuthal angle ϕ is measured in the x - y plane. Pseudorapidity is given by $\eta \equiv -\ln[\tan(\theta/2)]$.

The CMS detector [17] has cylindrical symmetry around the pp beam axis with tracking and muon detectors covering the pseudorapidity range $|\eta| < 2.4$. The tracking system, used to measure the trajectory and momentum of charged particles, consists of multilayered silicon pixel and strip detectors in a 3.8 T solenoidal magnetic field. Particle energies are measured

with concentric electromagnetic and hadron calorimeters, which cover $|\eta| < 3.0$ and $|\eta| < 5.0$, respectively. Muon detectors consisting of wire chambers are embedded in the steel return yoke outside the solenoid. The trigger thresholds in a two-level trigger system are tuned to accept a few hundred data events per second from the pp interactions.

We select events with three or more leptons (including tau leptons) that are accepted by a trigger requiring two light leptons, which may be electrons or muons. Any opposite-sign, same-flavor (OSSF) pair of electrons or muons has to have an invariant mass $m_{\ell\ell} > 12 \text{ GeV}$. This requirement removes low-mass bound states and $\gamma^* \rightarrow \ell^+ \ell^-$ production.

Electrons and muons are reconstructed using quantities from the tracker, calorimeter, and muon systems. Details of reconstruction and identification can be found in Ref. [18] for electrons and in Ref. [19] for muons. We require that at least one electron or muon in each event has transverse momentum of $p_T > 20 \text{ GeV}$. Additional electrons and muons must have $p_T > 10 \text{ GeV}$ and all of them must be within $|\eta| < 2.4$.

The majority of hadronic decays of tau leptons (τ_h) yield either a single charged track (one-prong) or three charged tracks (three-prong), occasionally with additional electromagnetic energy from neutral pion decays. Both one- and three-prong τ_h candidates are used in this analysis if they have $p_T > 20 \text{ GeV}$, reconstructed with the “hadron plus strips” method [20]. Leptonically decaying taus are included with other electrons and muons.

To ensure that electrons, muons, and τ_h candidates are isolated, we use a particle-flow (PF) algorithm [21, 22] to identify the source of transverse energy deposits in the trackers and calorimeters. We then sum the contribution in a cone of radius 0.3 in $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ around the candidate and subtract the lepton p_T to calculate E_{cone} . The energy from additional proton-proton collisions that occur simultaneously is subtracted [18, 23]. For electrons and muons, we divide the summed energy by the lepton p_T to find the relative isolation $I_{\text{rel}} = E_{\text{cone}} / p_T$, which has to be less than 0.15. We require $E_{\text{cone}} < 2 \text{ GeV}$ for τ_h candidates.

We use jets reconstructed from all of the PF candidates [23] using the anti- k_T algorithm [24] with a distance parameter of 0.5, that have $|\eta| < 2.5$ and $p_T > 30 \text{ GeV}$. Jets are required to be a distance $\Delta R > 0.3$ away from any isolated electron, muon, or τ_h candidate. To determine if the jet originated from a bottom quark, we use the combined secondary-vertex algorithm, which calculates a likelihood discriminant using the track impact parameter and secondary-vertex information. This discrimination selects heavy-flavor jets with an efficiency of 70% and suppresses light-flavor jets with a misidentification probability of 1.5% [25].

Monte Carlo (MC) simulations are used to estimate some of the SM backgrounds and to understand the efficiency and acceptance of the signal models we are investigating. The SM background samples are generated using MADGRAPH [26] with parton showering and fragmentation modeled using PYTHIA (version 6.420) [27] and passed through a GEANT4-based [28] representation of the CMS detector. Signal samples [16] are generated with MADGRAPH and PYTHIA and passed through the CMS fast-simulation package [29]. Next-to-leading- and next-to-leading-log-order cross sections and their uncertainties for the SUSY signal processes are from the LHC SUSY cross sections working group [30–34].

Multilepton signals have two main sources of backgrounds, the first arising from processes that produce genuine multilepton events. The most significant examples are WZ and ZZ production, but rare processes such as $t\bar{t} W^\pm$ and $t\bar{t} Z$ can also contribute. We assess the contribution from these processes using samples simulated by MADGRAPH. For WZ and ZZ production, these simulated samples have been validated in control regions in data. For the rarer background processes, we rely solely on simulation.

The second source originates from objects that are misclassified as prompt, isolated leptons, but are actually hadrons, leptons from a hadron decay (heavy- or light-flavored), etc. Misidentified leptons are classified in three categories in our analysis: misidentified light leptons (electrons and muons), misidentified τ_h leptons, and light leptons originating from asymmetric internal conversions.

We estimate the contribution of misidentified light leptons by measuring the number of isolated tracks and applying a scale factor between isolated leptons and isolated tracks. These scale factors are measured in control regions that contain leptonically decaying Z-bosons and a third, isolated track. The scale factor is then the probability for the third track to pass the lepton identification criteria. We find the scale factors to be $(0.9 \pm 0.2)\%$ for electrons and $(0.7 \pm 0.2)\%$ for muons. The scale factors are applied to the sideband region with two light leptons and an isolated track. The scale factors depend on the heavy-flavor content in the different signal regions changes. We parametrize this dependence as a function of the impact parameter distribution of non-isolated tracks. The $t\bar{t}$ contribution here is taken from simulation.

The τ_h misidentification rate is measured in jet-dominated data by comparing the number of τ_h candidates in the signal region defined by $E_{\text{cone}} < 2 \text{ GeV}$ to the number of non-isolated τ_h candidates, which have $6 < E_{\text{cone}} < 30 \text{ GeV}$. We measure this misidentification rate to have an average value of 15% and assign a systematic uncertainty of 30% based on the variation in different control samples. We apply this rate to the sideband region with two light leptons and one non-isolated τ_h candidate.

Another source of background leptons are internal conversions, where a virtual photon decays promptly to a dilepton pair. These conversions produce muons almost as often as electrons. In the case of asymmetric conversions, where one lepton has very low p_T and/or does not pass the selection criteria, Drell–Yan type processes can lead to a significant background for three lepton signatures. We measure the conversion factors of photons to light leptons in a control region where no new physics is expected (low E_T^{miss} and low hadronic activity). The ratio of the number of $\ell^+\ell^-\ell^\pm$ candidates to the number of $\ell^+\ell^-\gamma$ candidates in the Z boson decays defines the conversion factor, which is $2.1\% \pm 0.3\%$ ($0.5\% \pm 0.1\%$) for electrons (muons) [14]. These uncertainties are statistical only. We assign systematic uncertainties of 100% to these conversion factors from our underlying assumption of proportionality between virtual and on-shell photons, as well as our inability to remove misidentified photons from sideband regions.

A systematic uncertainty of 4.4% in the normalization of the simulated samples accounts for imperfect knowledge of the integrated luminosity of the data sample [35]. Signal cross sections have varying uncertainties from 15% to 51% in the range of stop masses between 250 GeV and 1.5 TeV, which come from the parton distribution function uncertainties and the renormalization and factorization scale uncertainties [36]. We scale the WZ and ZZ simulation samples to match data in control regions. The overall systematic uncertainty on WZ and ZZ contributions to the signal regions varies between 15% and 30% depending on the kinematics, and is the combination of the normalization uncertainties with efficiency and resolution uncertainties. Muon identification efficiency uncertainty is 11% at muon p_T of 10 GeV and 0.2% at 100 GeV. For electrons the uncertainties are 14% at 10 GeV and 0.6% at 100 GeV. The uncertainty on the efficiency of the bottom-quark tagger is 6%. The uncertainty on the E_T^{miss} resolution contributes a 4% uncertainty and the jet energy scale uncertainty contributes 0.5% in our background estimates [37]. An uncertainty of 50% for the $t\bar{t}$ background contribution is due to the low event counts in the isolation distributions in high- S_T bins, which are used to validate the misidentification rate in the $t\bar{t}$ simulation sample. We apply a 50% uncertainty to the normalization of all rare processes.

Table 1: Observed yields for three- and four-lepton events from 19.5 fb^{-1} recorded in 2012. The channels are broken down by the total number of leptons (N_L), the number of τ_h candidates (N_τ), and the S_T . Expected yields are the sum of simulation and estimates of backgrounds from data in each channel. SR1–SR4 require a b-tagged jet and veto events containing Z bosons. SR5–SR8 contain events that either contain a Z boson or have no b-tagged jet. The channels are mutually exclusive. The uncertainties include both statistical and systematic uncertainties. The S_T values are given in GeV.

SR	N_L	N_τ	$0 < S_T < 300$		$300 < S_T < 600$		$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
			obs	exp	obs	exp	obs	exp	obs	exp	obs	exp
SR1	3	0	116	123 ± 50	130	127 ± 54	13	18.9 ± 6.7	1	1.43 ± 0.51	0	0.208 ± 0.096
SR2	3	≥ 1	710	698 ± 287	746	837 ± 423	83	97 ± 48	3	6.9 ± 3.9	0	0.73 ± 0.49
SR3	4	0	0	0.186 ± 0.074	1	0.43 ± 0.22	0	0.19 ± 0.12	0	0.037 ± 0.039	0	0.000 ± 0.021
SR4	4	≥ 1	1	0.89 ± 0.42	0	1.31 ± 0.48	0	0.39 ± 0.19	0	0.019 ± 0.026	0	0.000 ± 0.021
SR5	3	0	—	—	—	—	165	174 ± 53	16	21.4 ± 8.4	5	2.18 ± 0.99
SR6	3	≥ 1	—	—	—	—	276	249 ± 80	17	19.9 ± 6.8	0	1.84 ± 0.83
SR7	4	0	—	—	—	—	5	8.2 ± 2.6	2	0.96 ± 0.37	0	0.113 ± 0.056
SR8	4	≥ 1	—	—	—	—	2	3.8 ± 1.3	0	0.34 ± 0.16	0	0.040 ± 0.033

We define eight signal regions (SRs) depending on the total number of leptons and the number of τ_h candidates in the event, which are defined in Table 1. Since our signal does not contain any Z bosons and does contain two to four bottom quarks, in SR1–SR4 we veto events in which any OSSF dilepton pair has an invariant mass consistent with that of the Z boson (75–105 GeV) and require at least one b-tagged jet. Each of these eight SRs is subsequently divided into five bins in S_T : [0–300], [300–600], [600–1000], [1000–1500], and [>1500] GeV. We gain additional sensitivity in regions with $S_T > 600$ GeV by removing the b-tag and Z-veto requirements for events, so the SR5–SR8 contain the events that fail one or both of these requirements.

The observed and expected yields for SR1–SR8 are shown in Table 1. We also show the S_T distribution for SR1 in Fig. 1 with the background expectations from different sources shown separately. Data are in good agreement with the SM predictions in all signal regions.

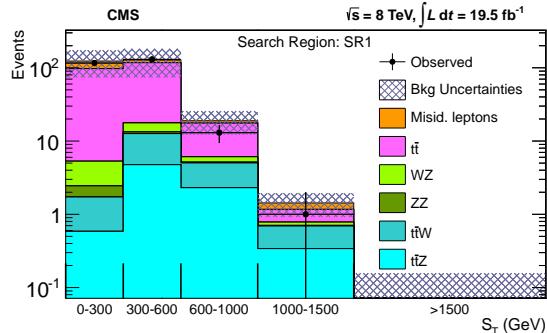


Figure 1: The S_T distributions for SR1 including observed yields and background contributions.

To demonstrate how natural SUSY might manifest itself with RPV couplings, we examine a stop RPV model where the light stop decays to a top quark and intermediate on- or off-shell bino, $\tilde{t}_1 \rightarrow \tilde{\chi}_1^{0*} + t$. The bino then decays to two leptons and a neutrino through the leptonic R-parity violating interactions, $\tilde{\chi}_1^{0*} \rightarrow \ell_i + \nu_j + \ell_k$ and $\nu_i + \ell_j + \ell_k$, or through the semileptonic R-parity violating interactions, $\tilde{\chi}_1^{0*} \rightarrow \ell_i + q_j + q_k$ and $\nu_i + q_j + q_k$, where the indices i, j, k refer to those appearing in Eq. 1. The stop is assumed to be right-handed and RPV couplings are large enough that all decays are prompt.

We generate simulated samples to evaluate models with simplified mass spectra and the only non-zero leptonic RPV couplings λ_{122} or λ_{233} . The stop masses in these samples range from 700–1250 GeV in 50 GeV steps, and bino masses range from 100–1300 GeV in 100 GeV steps. In a model with only the semi-leptonic RPV coupling λ'_{233} non-zero, we use stop masses 300–

Table 2: Kinematically allowed stop decay modes with RPV coupling λ'_{233} . The allowed neutralino decay modes for $m_t < m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1}$ are $\tilde{\chi}_1^0 \rightarrow \mu t \bar{b}$ and $\nu b \bar{b}$.

Label	Kinematic region	Decay mode
A	$m_t < m_{\tilde{t}_1} < 2m_t, m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow t\nu b\bar{b}$
B	$2m_t < m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow t\mu t\bar{b}$ or $t\nu b\bar{b}$
C	$m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_{W^\pm} + m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow \ell\nu b\tilde{\chi}_1^0$ or $j\nu b\tilde{\chi}_1^0$
D	$m_{W^\pm} + m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_t + m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \rightarrow bW^\pm\tilde{\chi}_1^0$
E	$m_t + m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1}$	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$

1000 GeV in 50 GeV steps and bino masses 200–850 GeV in 50 GeV steps. In both cases, slepton and sneutrino masses are 200 GeV above the bino mass. Other particles are irrelevant to the interpretation of our results in these models.

To calculate our limits, we divide the channels shown in Table 1 by lepton flavor and perform a counting experiment using the observed event yields, the background expectations, and the signal expectations as inputs. We combine the limits from the channels with the highest individual sensitivities, which we require in aggregate to contain at least 90% of the signal acceptance at the relevant model grid point [14]. We use the LHC-type CL_s method in the limit calculation, which uses the ratio of profiled likelihoods as the test statistic [38, 39]. We introduce log-normal nuisance parameters to account for uncertainties on the signal and background estimates.

For all of the couplings, we expect two bottom-quark jets and up to two leptons from the two top quarks. For the leptonic RPV coupling λ_{122} , we also expect four electrons or muons. For leptonic coupling λ_{233} , we expect four leptons with up to two muons and the rest tau leptons. We use all tau lepton decay channels. For the semileptonic coupling λ'_{233} , we expect up to two muons, as well as two top quarks and two bottom quarks.

In the models with leptonic couplings, we find that the limits are approximately independent of the bino mass, and, using the conservative minus-one-standard-deviation result where the bino mass is 200 GeV, we are able to exclude models with the stop mass below 1020 GeV when λ_{122} is non-zero, and below 820 GeV when λ_{233} is non-zero. These limits are shown in Fig. 2. There is a change in kinematics at the line $m_{\tilde{\chi}_1^0} = m_{\tilde{t}_1} - m_t$, below which the stop decay is two-body, while above it is a four-body decay. Near this line, the $\tilde{\chi}_1^0$ and top are produced almost at rest, which results in soft leptons, reducing our acceptance. This loss of acceptance is more pronounced in the $\lambda_{233} \neq 0$ case and causes the loss of observed sensitivity near the line at $m_{\tilde{\chi}_1^0} = 800$ GeV. This feature is enhanced in the observed limit because the data has a lower number of events in the relevant signal regions than the simulated signal samples.

In the semileptonic RPV model, which has non-zero λ'_{233} , the kinematics of the decay are more complicated. These different kinematic regions are described in Table 2. The most significant effect is when the decay $\tilde{\chi}_1^0 \rightarrow \mu + t + b$ is kinematically disfavored, which reduces the number of available leptons. The different regions where this effect is pronounced drive the shape of the exclusion for λ'_{233} . The area inside the curve is excluded. The observed limit is stronger than the expected one, which allows the observed exclusion region to reach into the regime where the bino decouples.

We have performed a search for RPV supersymmetry in models with top-squark pair production using a variety of multilepton final states. We see good agreement between observations and SM expectations. We set stringent limits on the top-squark mass in models with leptonic

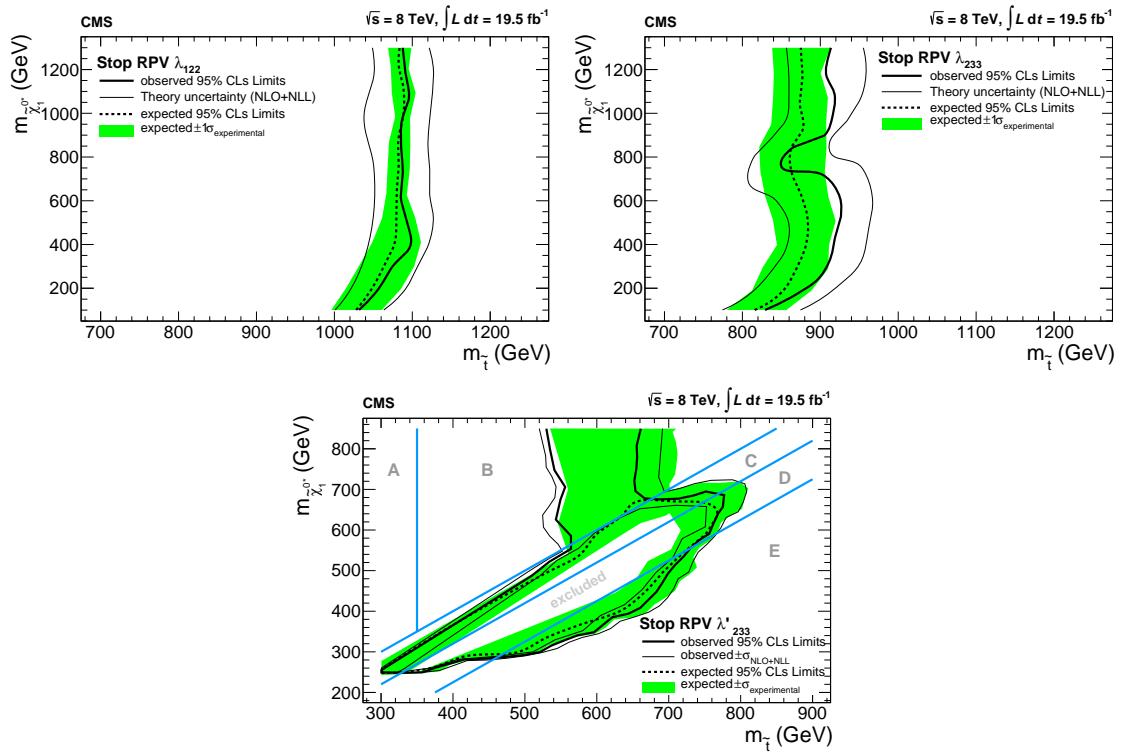


Figure 2: The 95% confidence level limits in the stop mass and bino mass plane for models with RPV couplings λ_{122} , λ_{233} , and λ'_{233} . For the couplings λ_{122} and λ_{233} , the region to the left of the curve is excluded. For λ'_{233} , the region inside the curve is excluded. The different regions, A, B, C, D, and E, for the λ'_{233} exclusion result from different stop decay products as explained in Table 2.

RPV couplings λ_{122} and λ_{233} . For a bino mass of 200 GeV, these limits are 1020 GeV and 820 GeV, respectively. We also set limits in a model with the semi-leptonic RPV coupling λ'_{233} .

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEPCenter, IPST, STAR and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

References

- [1] H. P. Nilles, “Supersymmetry, Supergravity and Particle Physics”, *Phys. Rept.* **110** (1984) 1, doi:[10.1016/0370-1573\(84\)90008-5](https://doi.org/10.1016/0370-1573(84)90008-5).
- [2] H. E. Haber and G. L. Kane, “The Search for Supersymmetry: Probing Physics Beyond the Standard Model”, *Phys. Rept.* **117** (1985) 75, doi:[10.1016/0370-1573\(85\)90051-1](https://doi.org/10.1016/0370-1573(85)90051-1).
- [3] G. R. Farrar and P. Fayet, “Phenomenology of the Production, Decay, and Detection of New Hadronic States Associated with Supersymmetry”, *Phys. Lett. B* **76** (1978) 575, doi:[10.1016/0370-2693\(78\)90858-4](https://doi.org/10.1016/0370-2693(78)90858-4).
- [4] R. Barbier et al., “R-parity violating supersymmetry”, *Phys. Rept.* **420** (2005) 1, doi:[10.1016/j.physrep.2005.08.006](https://doi.org/10.1016/j.physrep.2005.08.006), arXiv:[hep-ph/0406039](https://arxiv.org/abs/hep-ph/0406039).
- [5] Particle Data Group, J. Beringer et al., “Review of Particle Physics”, *Phys. Rev. D* **86** (2012) 010001, doi:[10.1103/PhysRevD.86.010001](https://doi.org/10.1103/PhysRevD.86.010001).
- [6] ALEPH Collaboration, “Search for supersymmetric particles with R-parity violating decays in e^+e^- collisions at \sqrt{s} up to 209 GeV”, *Eur. Phys. J. C* **31** (2003) 1, doi:[10.1140/epjc/s2003-01311-5](https://doi.org/10.1140/epjc/s2003-01311-5), arXiv:[hep-ex/0210014](https://arxiv.org/abs/hep-ex/0210014).
- [7] DELPHI Collaboration, “Search for supersymmetric particles assuming R-parity nonconservation in e+ e- collisions at $\sqrt{s} = 192$ GeV to 208 GeV”, *Eur. Phys. J. C* **36** (2004) 1, doi:[10.1140/epjc/s2004-01881-6](https://doi.org/10.1140/epjc/s2004-01881-6), arXiv:[hep-ex/0406009](https://arxiv.org/abs/hep-ex/0406009).
- [8] L3 Collaboration, “Search for R parity violating decays of supersymmetric particles in e^+e^- collisions at LEP”, *Phys. Lett. B* **524** (2002) 65, doi:[10.1016/S0370-2693\(01\)01367-3](https://doi.org/10.1016/S0370-2693(01)01367-3), arXiv:[hep-ex/0110057](https://arxiv.org/abs/hep-ex/0110057).

- [9] D0 Collaboration, “Search for R-parity violating supersymmetry via the $LL\bar{E}$ couplings λ_{121} , λ_{122} or λ_{133} in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Lett. B* **638** (2006) 441, doi:10.1016/j.physletb.2006.05.077, arXiv:hep-ex/0605005.
- [10] CDF Collaboration, “Search for anomalous production of multilepton events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Rev. Lett.* **98** (2007) 131804, doi:10.1103/PhysRevLett.98.131804, arXiv:0706.4448.
- [11] H1 Collaboration, “A search for squarks of R-parity-violating SUSY at HERA”, *Z. Phys. C* **71** (1996) 211, doi:10.1007/BF02906978, arXiv:hep-ex/9604006.
- [12] ZEUS Collaboration, “Search for stop production in R-parity-violating supersymmetry at HERA”, *Eur. Phys. J. C* **50** (2007) 269, doi:10.1140/epjc/s10052-007-0240-8, arXiv:hep-ex/0611018.
- [13] CMS Collaboration, “Search for Physics Beyond the Standard Model Using Multilepton Signatures in pp Collisions at $\sqrt{s} = 7$ TeV”, *Phys. Lett. B* **704** (2011) 411, doi:10.1016/j.physletb.2011.09.047, arXiv:1106.0933.
- [14] CMS Collaboration, “Search for anomalous production of multilepton events in pp collisions at $\sqrt{s} = 7$ TeV”, *JHEP* **06** (2012) 169, doi:10.1007/JHEP06(2012)169, arXiv:1204.5341.
- [15] ATLAS Collaboration, “Search for R-parity-violating supersymmetry in events with four or more leptons in $\sqrt{s} = 7$ TeV pp collisions with the ATLAS detector”, *JHEP* **1212** (2012) 124, doi:10.1007/JHEP12(2012)124, arXiv:1210.4457.
- [16] J. A. Evans and Y. Kats, “LHC Coverage of RPV MSSM with Light Stops”, *JHEP* **1304** (2013) 028, doi:10.1007/JHEP04(2013)028, arXiv:1209.0764.
- [17] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **03** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [18] CMS Collaboration, “Electron Reconstruction and Identification at $\sqrt{s} = 7$ TeV”, CMS Physics Analysis Summary CMS-PAS-EGM-10-004, (2010).
- [19] CMS Collaboration, “Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV”, *JINST* **7** (2012) P10002, doi:10.1088/1748-0221/7/10/P10002, arXiv:1206.4071.
- [20] CMS Collaboration, “Performance of τ -lepton reconstruction and identification in CMS”, *JINST* **7** (2012) P01001, doi:10.1088/1748-0221/7/01/P01001, arXiv:1109.6034.
- [21] CMS Collaboration, “Study of tau reconstruction algorithms using pp collisions data collected at $\sqrt{s} = 7$ TeV”, CMS Physics Analysis Summary CMS-PAS-PFT-10-004, (2010).
- [22] CMS Collaboration, “CMS Strategies for tau reconstruction and identification using particle-flow techniques”, CMS Physics Analysis Summary CMS-PAS-PFT-08-001, (2009).
- [23] CMS Collaboration, “Commissioning of the Particle-Flow Reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV”, CMS Physics Analysis Summary CMS-PAS-PFT-10-002, (2010).

- [24] M. Cacciari, G. P. Salam, and G. Soyez, “The anti- k_t jet clustering algorithm”, *JHEP* **04** (2008) 063, doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189.
- [25] CMS Collaboration, “Identification of b-quark jets with the CMS experiment”, *JINST* **8** (2013) P04013, doi:10.1088/1748-0221/8/04/P04013, arXiv:1211.4462.
- [26] F. Maltoni and T. Stelzer, “MadEvent: Automatic event generation with MadGraph”, *JHEP* **02** (2003) 027, doi:10.1088/1126-6708/2003/02/027, arXiv:hep-ph/0208156.
- [27] T. Sjöstrand, S. Mrenna, and P. Z. Skands, “A Brief Introduction to PYTHIA 8.1”, *Comput. Phys. Commun.* **178** (2008) 852, doi:10.1016/j.cpc.2008.01.036, arXiv:0710.3820.
- [28] GEANT4 Collaboration, “GEANT4—a simulation toolkit”, *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.
- [29] CMS Collaboration, “Fast simulation of the CMS detector”, *J. Phys. Conf. Ser.* **219** (2010) 032053, doi:10.1088/1742-6596/219/3/032053.
- [30] W. Beenakker et al., “Production of charginos, neutralinos, and sleptons at hadron colliders”, *Phys. Rev. Lett.* **83** (1999) 3780, doi:10.1103/PhysRevLett.83.3780, arXiv:hep-ph/9906298.
- [31] A. Kulesza and L. Motyka, “Threshold resummation for squark-antisquark and gluino-pair production at the LHC”, *Phys. Rev. Lett.* **102** (2009) 111802, doi:10.1103/PhysRevLett.102.111802, arXiv:0807.2405.
- [32] A. Kulesza and L. Motyka, “Soft gluon resummation for the production of gluino-gluino and squark-antisquark pairs at the LHC”, *Phys. Rev. D* **80** (2009) 095004, doi:10.1103/PhysRevD.80.095004, arXiv:0905.4749.
- [33] W. Beenakker et al., “Soft-gluon resummation for squark and gluino hadroproduction”, *JHEP* **12** (2009) 041, doi:10.1088/1126-6708/2009/12/041, arXiv:0909.4418.
- [34] W. Beenakker et al., “Squark and Gluino Hadroproduction”, *Int. J. Mod. Phys. A* **26** (2011) 2637, doi:10.1142/S0217751X11053560, arXiv:1105.1110.
- [35] “CMS Luminosity Based on Pixel Cluster Counting - Summer 2012 Update”, Technical Report CMS-PAS-LUM-12-001, CERN, Geneva, (2012).
- [36] M. Krämer et al., “Supersymmetry production cross sections in pp collisions at $\sqrt{s} = 7$ TeV”, (2012). arXiv:1206.2892.
- [37] CMS Collaboration, “Determination of jet energy calibration and transverse momentum resolution in CMS”, *JINST* **6** (2011) P11002, doi:10.1088/1748-0221/6/11/P11002.
- [38] ATLAS and CMS Collaboration, “Procedure for the LHC Higgs boson search combination in Summer 2011”, Technical Report CMS-NOTE-2011-005, ATLAS/CMS, Geneva, (2011).
- [39] T. Junk, “Confidence Level Computation for Combining Searches with Small Statistics”, *Nucl. Instrum. Meth. A* **434** (1999) 435, doi:10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan¹, M. Friedl, R. Frühwirth¹, V.M. Ghete, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, I. Mikulec, D. Rabady², B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz¹

National Centre for Particle and High Energy Physics, Minsk, Belarus

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium

S. Alderweireldt, M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, Z. Staykova, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, A. Kalogeropoulos, J. Keaveney, M. Maes, A. Olbrechts, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium

B. Clerbaux, G. De Lentdecker, L. Favart, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, A. Mohammadi, L. Perniè, T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang

Ghent University, Ghent, Belgium

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Dildick, G. Garcia, B. Klein, J. Lellouch, A. Marinov, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, S. Walsh, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium

S. Basegmez, C. Beluffi³, G. Bruno, R. Castello, A. Caudron, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giannanco⁴, J. Hollar, P. Jez, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, A. Popov⁵, M. Selvaggi, J.M. Vizan Garcia

Université de Mons, Mons, Belgium

N. Belyi, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

G.A. Alves, M. Correa Martins Junior, T. Martins, M.E. Pol, M.H.G. Souza

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

W.L. Aldá Júnior, W. Carvalho, J. Chinellato⁶, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, M. Malek, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁶, A. Vilela Pereira

Universidade Estadual Paulista ^a, Universidade Federal do ABC ^b, São Paulo, Brazil

C.A. Bernardes^b, F.A. Dias^{a,7}, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, C. Lagana^a, P.G. Mercadante^b, S.F. Novaes^a, Sandra S. Padula^a

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

V. Genchev², P. Iaydjiev², S. Piperov, M. Rodozov, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, R. Hadjiiska, V. Kozuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China

J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

C. Asawatangtrakuldee, Y. Ban, Y. Guo, Q. Li, W. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia

C. Avila, C.A. Carrillo Montoya, L.F. Chaparro Sierra, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

Technical University of Split, Split, Croatia

N. Godinovic, D. Lelas, R. Plestina⁸, D. Polic, I. Puljak

University of Split, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, S. Duric, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

University of Cyprus, Nicosia, Cyprus

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

Charles University, Prague, Czech Republic

M. Finger, M. Finger Jr.

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

A.A. Abdelalim⁹, Y. Assran¹⁰, S. Elgammal⁹, A. Ellithi Kamel¹¹, M.A. Mahmoud¹², A. Radi^{13,14}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

M. Kadastik, M. Müntel, M. Murumaa, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

J. Hätkönen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland

T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France

M. Besancon, S. Choudhury, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, L. Millischer, A. Nayak, J. Rander, A. Rosowsky, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj¹⁵, P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, M. Haguenauer,

P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

J.-L. Agram¹⁶, J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte¹⁶, F. Drouhin¹⁶, J.-C. Fontaine¹⁶, D. Gelé, U. Goerlach, C. Goetzmann, P. Juillot, A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l’Institut National de Physique Nucléaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France

S. Gadrat

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France

S. Beauceron, N. Beaupere, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, L. Sgandurra, V. Sordini, Y. Tschudi, M. Vander Donckt, P. Verdier, S. Viret

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia

Z. Tsamalaidze¹⁷

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany

C. Autermann, S. Beranek, B. Calpas, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, K. Klein, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov⁵

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, K. Padeken, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, S. Thüer, M. Weber

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann², A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz¹⁸, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, F. Costanza, C. Diez Pardos, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, D. Horton, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, J. Leonard, K. Lipka, W. Lohmann¹⁸, B. Lutz, R. Mankel, I. Marfin, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, F. Nowak, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, R. Schmidt¹⁸, T. Schoerner-Sadenius, N. Sen, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

V. Blobel, H. Enderle, J. Erfle, U. Gebbert, M. Görner, M. Gosselink, J. Haller, K. Heine,

R.S. Höing, G. Kaussen, H. Kirschenmann, R. Klanner, R. Kogler, J. Lange, I. Marchesini, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, J. Sibille¹⁹, V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, D. Troendle, L. Vanelderen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff², F. Hartmann², T. Hauth², H. Held, K.H. Hoffmann, U. Husemann, I. Katkov⁵, J.R. Komaragiri, A. Kornmayer², P. Lobelle Pardo, D. Martschei, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece

G. Anagnostou, G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, A. Markou, C. Markou, E. Ntomari

University of Athens, Athens, Greece

L. Gouskos, T.J. Mertzimekis, A. Panagiotou, N. Saoulidou, E. Stiliaris

University of Ioánnina, Ioánnina, Greece

X. Aslanoglou, I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, E. Paradas

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary

G. Bencze, C. Hajdu, P. Hidas, D. Horvath²⁰, B. Radics, F. Sikler, V. Veszpremi, G. Vesztregombi²¹, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary

J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India

S.K. Swain²²

Panjab University, Chandigarh, India

S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Kaur, M.Z. Mehta, M. Mittal, N. Nishu, L.K. Saini, A. Sharma, J.B. Singh

University of Delhi, Delhi, India

Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, S. Malhotra, M. Naimuddin, K. Ranjan, P. Saxena, V. Sharma, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla, A. Topkar

Tata Institute of Fundamental Research - EHEP, Mumbai, India

T. Aziz, R.M. Chatterjee, S. Ganguly, S. Ghosh, M. Guchait²³, A. Gurtu²⁴, G. Kole,

S. Kumar, M. Maity²⁵, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage²⁶

Tata Institute of Fundamental Research - HECR, Mumbai, India

S. Banerjee, S. Dugad

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

H. Arfaei, H. Bakhshiansohi, S.M. Etesami²⁷, A. Fahim²⁸, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh²⁹, M. Zeinali

University College Dublin, Dublin, Ireland

M. Grunewald

INFN Sezione di Bari ^a, Università di Bari ^b, Politecnico di Bari ^c, Bari, Italy

M. Abbrescia^{a,b}, L. Barbone^{a,b}, C. Calabria^{a,b}, S.S. Chhibra^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, N. De Filippis^{a,c}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, B. Marangelli^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, N. Pacifico^a, A. Pompili^{a,b}, G. Pugliese^{a,c}, G. Selvaggi^{a,b}, L. Silvestris^a, G. Singh^{a,b}, R. Venditti^{a,b}, P. Verwilligen^a, G. Zito^a

INFN Sezione di Bologna ^a, Università di Bologna ^b, Bologna, Italy

G. Abbiendi^a, A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^{a,2}, M. Meneghelli^{a,b}, A. Montanari^a, F.L. Navarria^{a,b}, F. Odorici^a, A. Perrotta^a, F. Primavera^{a,b}, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b}, R. Travaglini^{a,b}

INFN Sezione di Catania ^a, Università di Catania ^b, Catania, Italy

S. Albergo^{a,b}, M. Chiorboli^{a,b}, S. Costa^{a,b}, F. Giordano^{a,2}, R. Potenza^{a,b}, A. Tricomi^{a,b}, C. Tuve^{a,b}

INFN Sezione di Firenze ^a, Università di Firenze ^b, Firenze, Italy

G. Barbagli^a, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, E. Focardi^{a,b}, S. Frosali^{a,b}, E. Gallo^a, S. Gonzi^{a,b}, V. Gori^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, A. Tropiano^{a,b}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo

INFN Sezione di Genova ^a, Università di Genova ^b, Genova, Italy

P. Fabbricatore^a, R. Musenich^a, S. Tosi^{a,b}

INFN Sezione di Milano-Bicocca ^a, Università di Milano-Bicocca ^b, Milano, Italy

A. Benaglia^a, F. De Guio^{a,b}, L. Di Matteo^{a,b}, S. Fiorenti^{a,b}, S. Gennai^a, A. Ghezzi^{a,b}, P. Govoni, M.T. Lucchini², S. Malvezzi^a, R.A. Manzoni^{a,b,2}, A. Martelli^{a,b,2}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, T. Tabarelli de Fatis^{a,b}

INFN Sezione di Napoli ^a, Università di Napoli 'Federico II' ^b, Università della Basilicata (Potenza) ^c, Università G. Marconi (Roma) ^d, Napoli, Italy

S. Buontempo^a, N. Cavallo^{a,c}, A. De Cosa^{a,b}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, L. Lista^a, S. Meola^{a,d,2}, M. Merola^a, P. Paolucci^{a,2}

INFN Sezione di Padova ^a, Università di Padova ^b, Università di Trento (Trento) ^c, Padova, Italy

P. Azzi^a, N. Bacchetta^a, D. Bisello^{a,b}, A. Branca^{a,b}, R. Carlin^{a,b}, P. Checchia^a, T. Dorigo^a, U. Dosselli^a, M. Galanti^{a,b,2}, F. Gasparini^{a,b}, U. Gasparini^{a,b}, P. Giubilato^{a,b}, A. Gozzelino^a, K. Kanishchev^{a,c}, S. Lacaprara^a, I. Lazzizzera^{a,c}, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b},

F. Montecassiano^a, M. Passaseo^a, J. Pazzini^{a,b}, M. Pegoraro^a, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, A. Triassi^a, P. Zotto^{a,b}, G. Zumerle^{a,b}

INFN Sezione di Pavia ^a, Università di Pavia ^b, Pavia, Italy

M. Gabusi^{a,b}, S.P. Ratti^{a,b}, C. Riccardi^{a,b}, P. Vitulo^{a,b}

INFN Sezione di Perugia ^a, Università di Perugia ^b, Perugia, Italy

M. Biasini^{a,b}, G.M. Bilei^a, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Nappi^{a,b†}, F. Romeo^{a,b}, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b}

INFN Sezione di Pisa ^a, Università di Pisa ^b, Scuola Normale Superiore di Pisa ^c, Pisa, Italy

K. Androsov^{a,30}, P. Azzurri^a, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c,2}, R. Dell'Orso^a, F. Fiori^{a,c}, L. Foà^{a,c}, A. Giassi^a, M.T. Grippo^{a,30}, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,30}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A.T. Serban^a, P. Spagnolo^a, P. Squillaciotti^a, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a, C. Vernieri^{a,c}

INFN Sezione di Roma ^a, Università di Roma ^b, Roma, Italy

L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b}, M. Diemoz^a, M. Grassi^{a,b,2}, E. Longo^{a,b}, F. Margaroli^{a,b}, P. Meridiani^a, F. Micheli^{a,b}, S. Nourbakhsh^{a,b}, G. Organtini^{a,b}, R. Paramatti^a, S. Rahatlou^{a,b}, L. Soffi^{a,b}

INFN Sezione di Torino ^a, Università di Torino ^b, Università del Piemonte Orientale (Novara) ^c, Torino, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c}, S. Argiro^{a,b}, M. Arneodo^{a,c}, C. Biino^a, N. Cartiglia^a, S. Casasso^{a,b}, M. Costa^{a,b}, N. Demaria^a, C. Mariotti^a, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, M. Musich^a, M.M. Obertino^{a,c}, G. Ortona^{a,b}, N. Pastrone^a, M. Pelliccioni^{a,2}, A. Potenza^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, A. Solano^{a,b}, A. Staiano^a, U. Tamponi^a

INFN Sezione di Trieste ^a, Università di Trieste ^b, Trieste, Italy

S. Belforte^a, V. Candelise^{a,b}, M. Casarsa^a, F. Cossutti^{a,2}, G. Della Ricca^{a,b}, B. Gobbo^a, C. La Licata^{a,b}, M. Marone^{a,b}, D. Montanino^{a,b}, A. Penzo^a, A. Schizzi^{a,b}, A. Zanetti^a

Kangwon National University, Chunchon, Korea

S. Chang, T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea

D.H. Kim, G.N. Kim, J.E. Kim, D.J. Kong, Y.D. Oh, H. Park, D.C. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea

J.Y. Kim, Zero J. Kim, S. Song

Korea University, Seoul, Korea

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, S.K. Park, Y. Roh

University of Seoul, Seoul, Korea

M. Choi, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

Sungkyunkwan University, Suwon, Korea

Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania

I. Grigelionis, A. Juodagalvis

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz³¹, R. Lopez-Fernandez,
J. Martinez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico

E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

University of Auckland, Auckland, New Zealand

D. Kofcheck

University of Canterbury, Christchurch, New Zealand

A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan

M. Ahmad, M.I. Asghar, J. Butt, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi,
M.A. Shah, M. Shoib

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki,
J. Krolikowski, M. Misiura, W. Wolszczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

N. Almeida, P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho,
M. Gallinaro, J. Rodrigues Antunes, J. Seixas², J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, P. Bunin, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov,
G. Kozlov, A. Lanev, A. Malakhov, V. Matveev, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov,
N. Skatchkov, V. Smirnov, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia

S. Evstyukhin, V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov,
V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia

Yu. Andreev, A. Dermenev, S. Glinenko, N. Golubev, M. Kirsanov, N. Krasnikov, A. Pashenkov,
D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, M. Erofeeva, V. Gavrilov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov,
A. Spiridonov, V. Stolin, E. Vlasov, A. Zhokin

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov,
A. Vinogradov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin⁷, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, V. Savrin, A. Snigirev

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

P. Adzic³², M. Djordjevic, M. Ekmedzic, D. Krpic³², J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

M. Aguilar-Benitez, J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas², N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, E. Navarro De Martino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, J.F. de Trocóniz

Universidad de Oviedo, Oviedo, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J. Bendavid, J.F. Benitez, C. Bernet⁸, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, S. Colafranceschi³³, D. d'Enterria, A. Dabrowski, A. David, A. De Roeck, S. De Visscher, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, S. Gowdy, R. Guida, J. Hammer, M. Hansen, P. Harris, C. Hartl, A. Hinzmann, V. Innocente, P. Janot, E. Karavakis, K. Kousouris, K. Krajczar, P. Lecoq, Y.-J. Lee, C. Lourenço, N. Magini, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M. Mulders, P. Musella, E. Nesvold, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, M. Plagge, L. Quertenmont, A. Racz, W. Reece, G. Rolandi³⁴, C. Rovelli³⁵, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³⁶, D. Spiga, M. Stoye, A. Tsirou, G.I. Veres²¹, J.R. Vlimant, H.K. Wöhri, S.D. Worm³⁷, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli,
S. König, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher,
G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, K. Freudenreich, C. Grab, D. Hits,
P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat,
C. Nägeli³⁸, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga,
M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov³⁹, B. Stieger, M. Takahashi, L. Tauscher[†],
A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber

Universität Zürich, Zurich, Switzerland

C. Amsler⁴⁰, V. Chiochia, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias,
P. Otiougova, P. Robmann, H. Snoek, S. Taroni, S. Tupputi, M. Verzetti

National Central University, Chung-Li, Taiwan

M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, M. Wang

Chulalongkorn University, Bangkok, Thailand

B. Asavapibhop, N. Suwonjandee

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci⁴¹, S. Cerci⁴², C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis,
G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut⁴³, K. Ozdemir,
S. Ozturk⁴¹, A. Polatoz, K. Sogut⁴⁴, D. Sunar Cerci⁴², B. Tali⁴², H. Topakli⁴¹, M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, G. Karapinar⁴⁵,
K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey

E. Gülmез, B. Isildak⁴⁶, M. Kaya⁴⁷, O. Kaya⁴⁷, S. Ozkorucuklu⁴⁸, N. Sonmez⁴⁹

Istanbul Technical University, Istanbul, Turkey

H. Bahtiyar⁵⁰, E. Barlas, K. Cankocak, Y.O. Günaydin⁵¹, F.I. Vardarlı, M. Yücel

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom

J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath,
H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold³⁷, K. Nirunpong, A. Poll, S. Senkin,
V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso⁵², K.W. Bell, A. Belyaev⁵², C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan,
K. Harder, S. Harper, J. Jackson, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-
Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom

R. Bainbridge, O. Buchmuller, D. Burton, D. Colling, N. Cripps, M. Cutajar, P. Dauncey,

G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas³⁷, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko³⁹, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi⁵³, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Sparrow, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Brunel University, Uxbridge, United Kingdom

M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, W. Martin, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA

J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA

O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

Boston University, Boston, USA

A. Avetisyan, T. Bose, C. Fantasia, A. Heister, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, J. St. John, L. Sulak

Brown University, Providence, USA

J. Alimena, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, A. Ferapontov, A. Garabedian, U. Heintz, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer

University of California, Davis, Davis, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, R. Nelson, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, S. Wilbur, R. Yohay

University of California, Los Angeles, USA

V. Andreev, D. Cline, R. Cousins, S. Erhan, P. Everaerts, C. Farrell, M. Felcini, J. Hauser, M. Ignatenko, C. Jarvis, G. Rakness, P. Schlein[†], E. Takasugi, P. Traczyk, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, G. Hanson, H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech⁵⁴, F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, C. George, F. Golf, J. Incandela, C. Justus, P. Kalavase, D. Kovalskyi, V. Krutelyov, S. Lowette, R. Magaña Villalba, N. Mccoll, V. Pavlunin, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

California Institute of Technology, Pasadena, USA

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, D. Kcira, Y. Ma, A. Mott, H.B. Newman, C. Rogan, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, Y.F. Liu, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA

J.P. Cumalat, B.R. Drell, W.T. Ford, A. Gaz, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA

J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, W. Hopkins, A. Khukhunaishvili, B. Kreis, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA

D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apolinari, L.A.T. Bauerick, A. Beretvas, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, L. Gray, D. Green, O. Gutsche, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko⁵⁵, C. Newman-Holmes, V. O'Dell, O. Prokofyev, N. Ratnikova, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, J.C. Yun

University of Florida, Gainesville, USA

D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic⁵⁶, G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA

V. Gaultney, S. Hewamanage, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA

T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA

M.M. Baarmann, B. Dorney, M. Hohlmann, H. Kalakhety, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA

M.R. Adams, L. Apanasevich, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, P. Kurt, F. Lacroix, D.H. Moon, C. O'Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak⁵⁰, B. Bilki⁵⁷, W. Clarida, K. Dilsiz, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya⁵⁸, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, H. Ogul, Y. Onel, F. Ozok⁵⁰, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin⁵⁹, K. Yi

Johns Hopkins University, Baltimore, USA

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gritsan, G. Hu, P. Maksimovic, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, R.P. Kenny III, M. Murray, D. Noonan, S. Sanders, R. Stringer, J.S. Wood

Kansas State University, Manhattan, USA

A.F. Barfuss, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze

Lawrence Livermore National Laboratory, Livermore, USA

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA

A. Baden, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Peterman, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, G. Bauer, W. Busza, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, Y. Kim, M. Klute, Y.S. Lai, A. Levin, P.D. Luckey, T. Ma, S. Nahm, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti, V. Zhukova

University of Minnesota, Minneapolis, USA

B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, J. Haupt, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

L.M. Cremaldi, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders, D. Summers

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, M. Eads, R. Gonzalez Suarez, J. Keller, I. Kravchenko, J. Lazo-Flores, S. Malik, F. Meier, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

J. Dolen, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio, Z. Wan

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, A. Massironi, D. Nash, T. Orimoto, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA

A. Anastassov, K.A. Hahn, A. Kubik, L. Lusito, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA

D. Berry, A. Brinkerhoff, K.M. Chan, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf

The Ohio State University, Columbus, USA

L. Antonelli, B. Bylsma, L.S. Durkin, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, G. Smith, C. Vuosalo, G. Williams, B.L. Winer, H. Wolfe

Princeton University, Princeton, USA

E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, D. Lopes Pegna, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, H. Saka, D. Stickland, C. Tully, J.S. Werner, S.C. Zenz, A. Zuranski

University of Puerto Rico, Mayaguez, USA

E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

Purdue University, West Lafayette, USA

E. Alagoz, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, K. Jung, O. Koybasi, M. Kress, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, F. Wang, L. Xu, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA

S. Guragain, N. Parashar

Rice University, Houston, USA

A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA

B. Betchart, A. Bodek, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, G. Petrillo, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianatos, G. Lungu, S. Malik, C. Mesropian

Rutgers, The State University of New Jersey, Piscataway, USA

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

University of Tennessee, Knoxville, USA

G. Cerizza, M. Hollingsworth, K. Rose, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA

O. Bouhali⁶⁰, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶¹, V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA

N. Akchurin, J. Damgov, C. Dragoiu, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, I. Volobouev

Vanderbilt University, Nashville, USA

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, W. Johns, C. Maguire, Y. Mao, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA

M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood

Wayne State University, Detroit, USA

S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane,
A. Sakharov

University of Wisconsin, Madison, USA

D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, E. Friis, M. Grothe, R. Hall-Wilton,
M. Herndon, A. Hervé, K. Kaadze, P. Klabbers, J. Klukas, A. Lanaro, R. Loveless, A. Mohapatra,
M.U. Mozer, I. Ojalvo, G.A. Pierro, G. Polese, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased

- 1: Also at Vienna University of Technology, Vienna, Austria
- 2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 3: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
- 4: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
- 5: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 6: Also at Universidade Estadual de Campinas, Campinas, Brazil
- 7: Also at California Institute of Technology, Pasadena, USA
- 8: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
- 9: Also at Zewail City of Science and Technology, Zewail, Egypt
- 10: Also at Suez Canal University, Suez, Egypt
- 11: Also at Cairo University, Cairo, Egypt
- 12: Also at Fayoum University, El-Fayoum, Egypt
- 13: Also at British University in Egypt, Cairo, Egypt
- 14: Now at Ain Shams University, Cairo, Egypt
- 15: Also at National Centre for Nuclear Research, Swierk, Poland
- 16: Also at Université de Haute Alsace, Mulhouse, France
- 17: Also at Joint Institute for Nuclear Research, Dubna, Russia
- 18: Also at Brandenburg University of Technology, Cottbus, Germany
- 19: Also at The University of Kansas, Lawrence, USA
- 20: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 21: Also at Eötvös Loránd University, Budapest, Hungary
- 22: Also at Tata Institute of Fundamental Research - EHEP, Mumbai, India
- 23: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
- 24: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 25: Also at University of Visva-Bharati, Santiniketan, India
- 26: Also at University of Ruhuna, Matara, Sri Lanka
- 27: Also at Isfahan University of Technology, Isfahan, Iran
- 28: Also at Sharif University of Technology, Tehran, Iran
- 29: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
- 30: Also at Università degli Studi di Siena, Siena, Italy
- 31: Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico
- 32: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
- 33: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
- 34: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
- 35: Also at INFN Sezione di Roma, Roma, Italy
- 36: Also at University of Athens, Athens, Greece
- 37: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom

-
- 38: Also at Paul Scherrer Institut, Villigen, Switzerland
 - 39: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
 - 40: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
 - 41: Also at Gaziosmanpasa University, Tokat, Turkey
 - 42: Also at Adiyaman University, Adiyaman, Turkey
 - 43: Also at Cag University, Mersin, Turkey
 - 44: Also at Mersin University, Mersin, Turkey
 - 45: Also at Izmir Institute of Technology, Izmir, Turkey
 - 46: Also at Ozyegin University, Istanbul, Turkey
 - 47: Also at Kafkas University, Kars, Turkey
 - 48: Also at Suleyman Demirel University, Isparta, Turkey
 - 49: Also at Ege University, Izmir, Turkey
 - 50: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
 - 51: Also at Kahramanmaraş Sütçü Imam University, Kahramanmaraş, Turkey
 - 52: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
 - 53: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
 - 54: Also at Utah Valley University, Orem, USA
 - 55: Also at Institute for Nuclear Research, Moscow, Russia
 - 56: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
 - 57: Also at Argonne National Laboratory, Argonne, USA
 - 58: Also at Erzincan University, Erzincan, Turkey
 - 59: Also at Yildiz Technical University, Istanbul, Turkey
 - 60: Also at Texas A&M University at Qatar, Doha, Qatar
 - 61: Also at Kyungpook National University, Daegu, Korea